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Assessment of soil trafficability across the agricultural region of the Canadian Prairies with the gridded climate data set

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ABSTRACT

The frequency of days with poor soil trafficability across the Canadian Prairies was determined from simulated soil moisture at soil polygon level during the growing season (April to September) with the Versatile Soil Moisture Budget (VSMB) model. Each soil polygon had a pre-determined critical soil moisture threshold in the first layer (0–5 cm) to trigger poor trafficability. The assessment of soil trafficability was limited to those polygons with good suitability rating for growing grain crops. For each of May, July and September, the polygon modelled soil moisture values were boot strapped into three percentile categories to reflect the highest risk (25th percentile), average conditions (50th percentile) and better than average conditions (75th percentile) for the entire climate period (1971 to 2000). We found that on average, soils with higher clay content (mostly those from eastern Manitoba, the northern fringes of the agricultural zone coinciding with the boreal forest zone and the Alberta Peace River region) had 5 to 9 days of poor trafficability at seeding time (May). In July, the zone with poor soil trafficability (close to two weeks) expanded northward to the Peace River Region of Alberta, northern Saskatchewan and eastern Manitoba. At harvest time (September), poor soil trafficability (> 10days) was concentrated in eastern Manitoba which also had the most days with poor soil trafficability at the start and mid-season months. The wet phase represented by the 75th percentile category showed that 10–14 days of poor trafficability can be expected on soil polygons with heavy textures. There were fewer days (1–4) with poor trafficability during dry years (the 25th percentile binned values). The soil trafficability maps generated from this study are a baseline for comparing trafficability levels under climate change scenarios and for planning agricultural activities.

1. Introduction

Periods of high soil moisture occur across Canada during every cropping season. High soil moisture not only damages crops, it also restricts field operations at critical times on the agricultural calendar. An issue that poor soil trafficability brings about is the inability of field equipment to traverse the soil surface without negatively impacting the soil physical properties (e.g. destruction of soil structure from compaction) and general disturbance of field conditions (seedbed and field roughness) necessary for crop production. The number of days that a soil can withstand field traffic is referred to as soil trafficability or field working days. According to Reeve and Fausey (1974), trafficability is "the ability to perform the required field operations in such a way as to create beneficial soil conditions or to complete a required operation expediently." Activities which are affected when a field is not trafficable include delays in seeding, spraying or harvesting. Poor soil trafficability especially at the start of the growing season can result in delayed or no seeding at all and leading to crop failure as was the case in parts of the prairie provinces in 2010 (Bonsal et al., 2017). When seeding is delayed, the growing season can become too short for the majority of the crops grown on the Canadian Prairies due to onset of frost in the autumn.

Soil trafficability can be related to specific soil properties and their interaction with soil moisture. As such, a soil has a critical soil moisture

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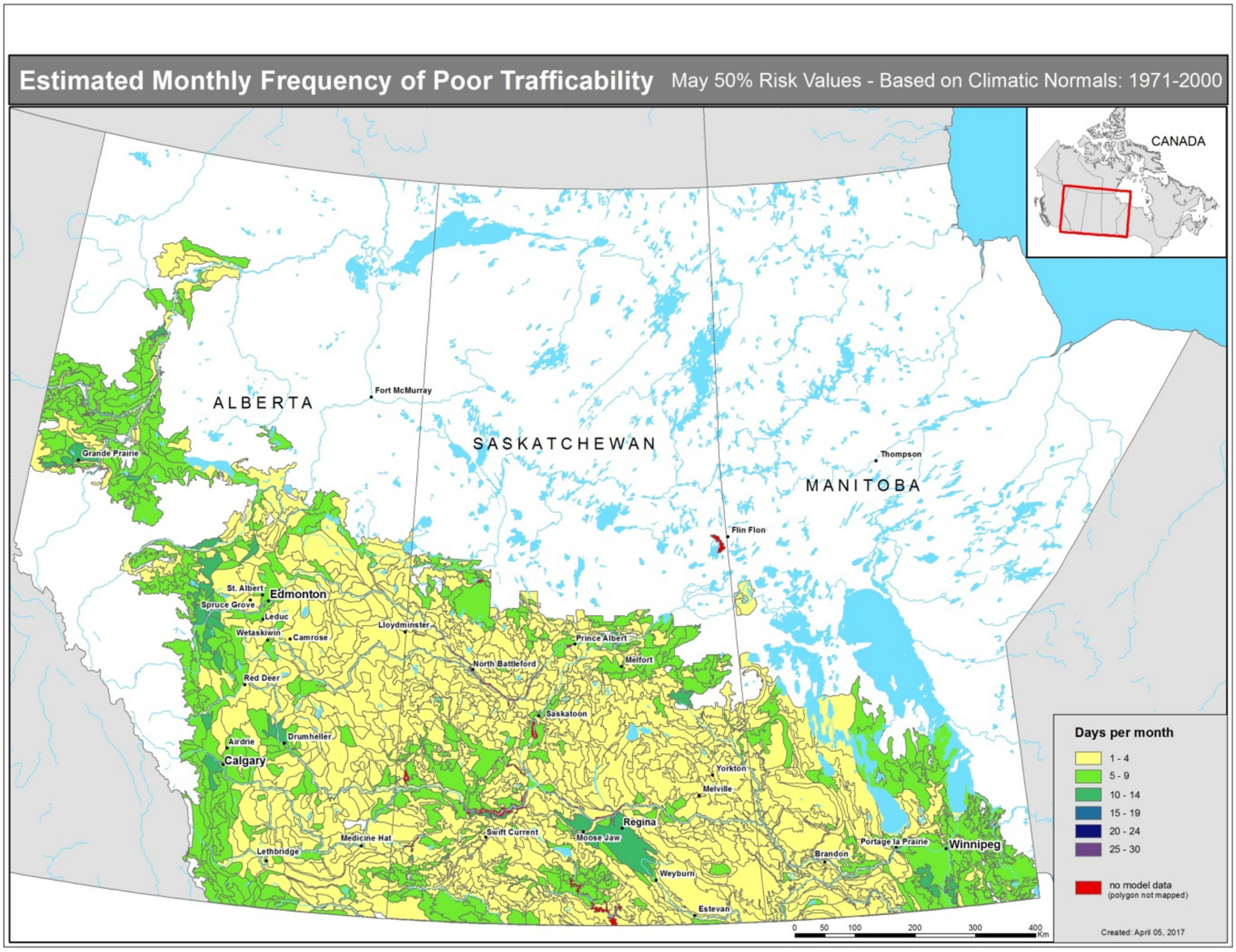

Fig. 1. The frequency of days with poor soil trafficability at seeding time (May) across the Prairie Provinces at the a) 50th Percentile b) 75th percentile and c) 25th percentile levels. Maps do not reflect local or regional changes to soil drainage such as tile, modified surface and regional drainage systems. Soil trafficabilty was not assessed in polygons where the areal extent of the suitable classes for growing crops was less than 20%.
a) 50th Percentile. The map shows the frequency of days with poor soil trafficability on average (1:2). Higher categories such as 10 to 14 days indicate that polygons in this category can experience poor soil trafficability up to two weeks during the month of May. A desirable outcome is fewer number of days (1-4) with poor trafficability in any given month to allow vehicular traffic to traverse the land.
b) 75th Percentile. The map shows the frequency of days with poor soil trafficability under conditions which are relatively wetter than average. These conditions come about due to excessive rain and snow melt in the spring.
c) 25th Percentile. The map shows the frequency of days with poor soil trafficability under relatively dry conditions (1:4). Under dry conditions the majority of the polygons are trafficable.

content beyond which the ability to safely travel on the soil is no longer feasible. A variety methods have been used to define the critical soil moisture content for soil trafficability. Most studies use soil moisture content relative to a specific soil property. Early work in Canada on trafficability/workdays used the critical soil moisture level of less than 97.5% of field capacity for heavy machinery and deep cultivation and greater than 90% of field capacity for lighter equipment and shallow cultivation (Baier, 1973). Other investigators have used values relative to a percent of available water holding capacity (Maton et al., 2007), or the plastic limit of the soil (Mueller et al., 2003; Tomasek et al., 2015). Paul and De Vries (1979) defined trafficability in relation to a critical soil water tension of 35 to 27 cm for a silty clay soil. A survey of the literature on thresholds for defining soil trafficability in Canada (Shaykewich, 2006, Pers. Comm) recommended a value slightly above field capacity for sandy soils and below 90% field capacity for clay oils. These recommendations were used by Sheppard et al. (2007) who found out that poor work days in the spring and fall resulted in more ammonia emission from manure than in the other seasons. The result from Sheppard et al. (2007) is an example of how delayed management of manure due to lack of soil trafficability can bring about unintended consequences. Shifts in trafficability may be introduced by tillage practices resulting in changes of the physical and productive capacity of the soil. In a study by Ozpinar and Cay (2005), three tillage practices (conventional, shallow and double discing) on a sandy loam soil from Turkey introduced changes in aggregate size distribution especially under double discing with positive effects on organic carbon accumulation

In Canada, the Versatile Soil Moisture Budget (VSMB) has been used successfully to estimate soil moisture levels in agricultural soils for a variety of applications such as irrigation scheduling, crop yield

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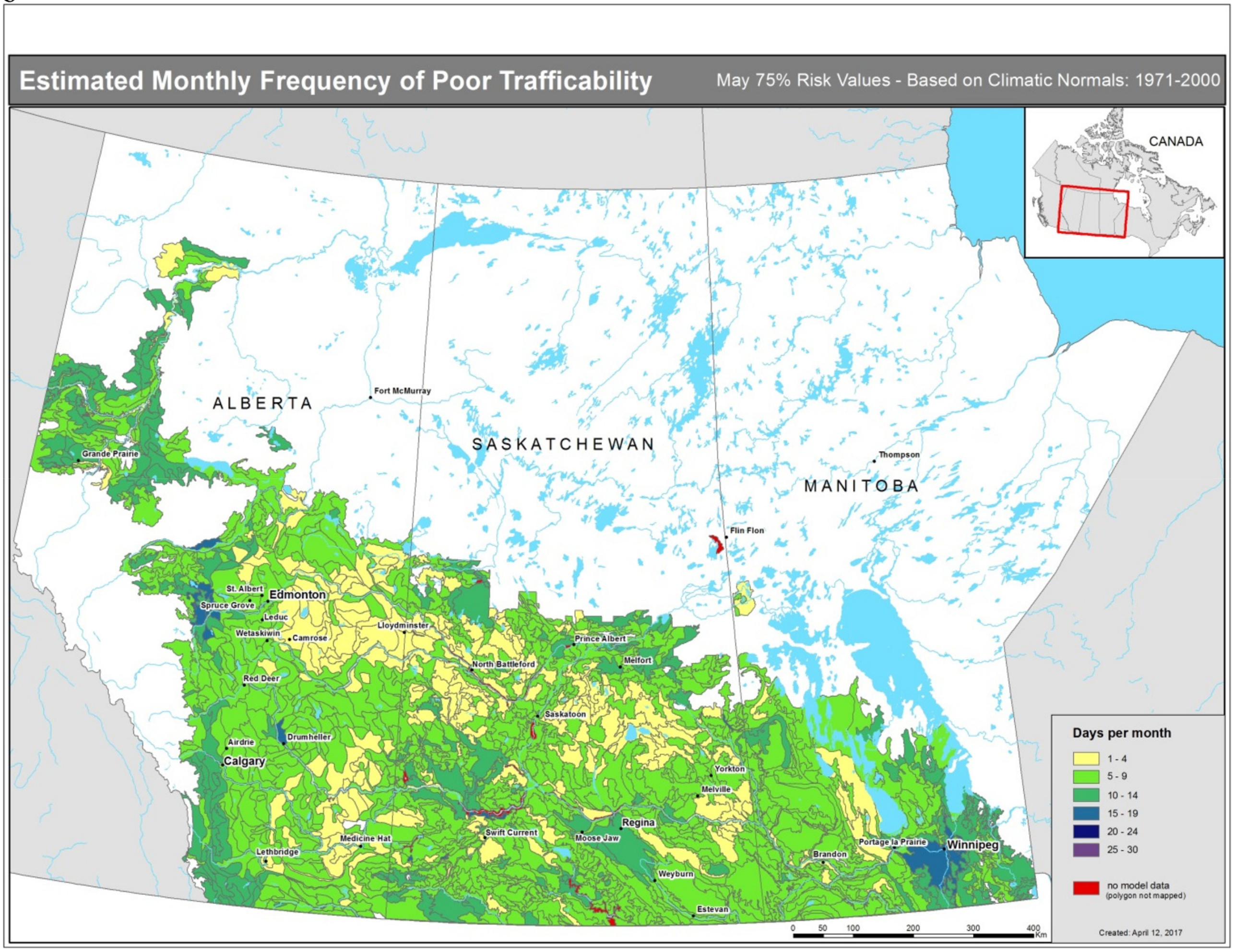

Fig. 1. (*continued*)

prediction and drought monitoring if direct measurements are not possible (Baier and Robertson, 1996; Malekian et al., 2014; Chipanshi et al., 2013). The VSMB has also been used to predict when soil moisture conditions would restrict field operations (Bootsma and De Jong, 1988; Sheppard et al., 2007; and Qian et al., 2013). Because of the wide application of the VSMB model in Canada, this model was an obvious choice in this study over other models such as the Variable Infiltration Capacity model (VIC) (Liang et al., 1994) which require more detailed site specific inputs.

Soil trafficability studies have implications on agricultural management under the present and future climates. In a study to understand the impact of climate change on Canadian agroclimatic indices under future climatic scenarios, Qian et al. (2013) applied the method of Bootsma and De Jong (1988) to determine whether the surface was trafficable or not at seeding time. Similarly, Rounsevell and Brignall (1994) working in England and Wales found that the predicted working days, or soil trafficability days, were useful in determining opportunities for tilling the soil in the autumn under a changed climate. The significance of soil trafficability was further demonstrated by Maton et al. (2007) who used it as one of the key factors for developing a model for estimating days which are agronomically suitable for seeding corn in France. Furthermore, Cooper et al., 1997 showed that under a changed climate in Scotland, there was a reduction of field workdays mostly due to an increase in winter rainfall.

In an attempt to provide baseline information for evaluating soil trafficability under a changed climate, this study was undertaken to provide soil trafficability information under average climatic conditions, worse than average conditions (25th percentile) and better than average conditions (75th percentile). In addition, the Interquartile Range (IQR) assessment was made to provide information on the range of variability of soil trafficability values in the study area under the observed climatic conditions. The objectives of this study were therefore twofold:

1) Conduct an assessment of soil trafficability for the Canadian prairie soils under the present climate regime against which future climate change assessments can be made and
2) Provide basic planning tools (maps) for assessing soil risks and sustainability for day-to-day agricultural activities.

The two objectives were realistic and timely because there has been very little information on the spatial and temporal patterns of the soil trafficability across the prairie region. Better resolved climate change scenario data sets at finer resolution have also become available and therefore, a need exists to provide baseline data for analyzing soil trafficability under future climatic conditions. This analysis is also an attempt to provide basic planning information for disaster amelioration and sustainable use of the soil resources by identifying those soil

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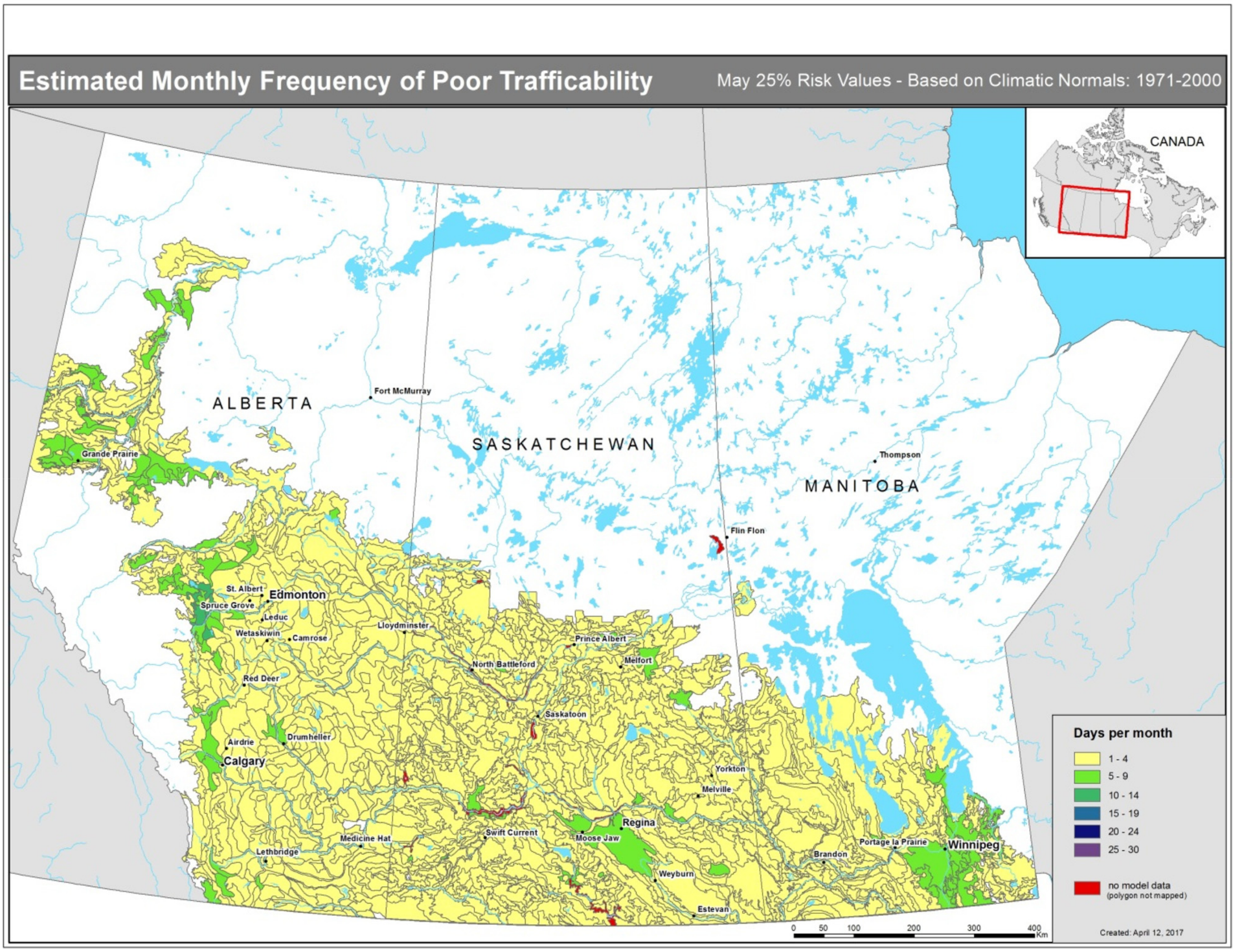

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polygons which are vulnerable. The analysis is intended to provide a generalized picture at the scale of 1:1,000,000 at which the soil input data sets existed. The methodology however can be used to assess trafficability at any scale as long as the input data sets are available.

2. Materials and methods

2.1. Study area

The analysis of trafficability under the present climate was limited to the agricultural extent of the Canadian prairies where soils are suitable for annual cropping. The Canadian Prairies (Fig. 1) has the largest agricultural land base in Canada and the region experiences some of the largest swings in climate extremes where drought and flooding within one growing season can be experienced (Steward et al., 2011). Politically, the Canadian Prairies is comprised of the provinces of Alberta, Saskatchewan and Manitoba moving from west to east. The predominant vegetation type is grassland in the south and prairie boreal forests to the north. Soils are typically chernozemic and change from brown to black, moving from the southwest to the northeast of the region. A full description of the Canadian Prairies can be found in Santibañez et al., 2010.

2.2. Data requirements

In order to arrive at the trafficability of the soil, soil moisture was first simulated using the soil physical characteristics of each polygon. There were more than one soil type in each polygon and polygons differed in size ranging from a few hectares to hundreds of hectares. Soil polygons consist of land areas defined in terms of similar landscape characteristics, soil type, salinity and climate (Soil Landscapes of Canada Working Group, 2006). Version 3.2 of the Soil Landscapes of Canada was used: http://sis.agr.gc.ca/cansis/nsdb/slc/v3.2/index.html. The soil physical characteristics for each soil layer, consisting of soil moisture content at saturation, field capacity and the wilting point, were obtained from the Canadian Soil Information Service (CanSIS) (Shields et al., 1991) at the 1:1Million scale. The natural soil horizons found in the CanSIS data base did not fit the discrete divisions of the soil profile normally required in any soil budget model run and therefore the values of the parameters for each layer from CanSIS were computed using an interpolation routine (Onofrei, 1987). There was more than one soil type in the polygon and therefore simulations were conducted on all the soils found in the polygon and the final value for the polygon was the weighted average. Climate data sets at the daily time step were used to drive the soil moisture budget model. Climate variables included daily total precipitation, maximum and minimum temperature.

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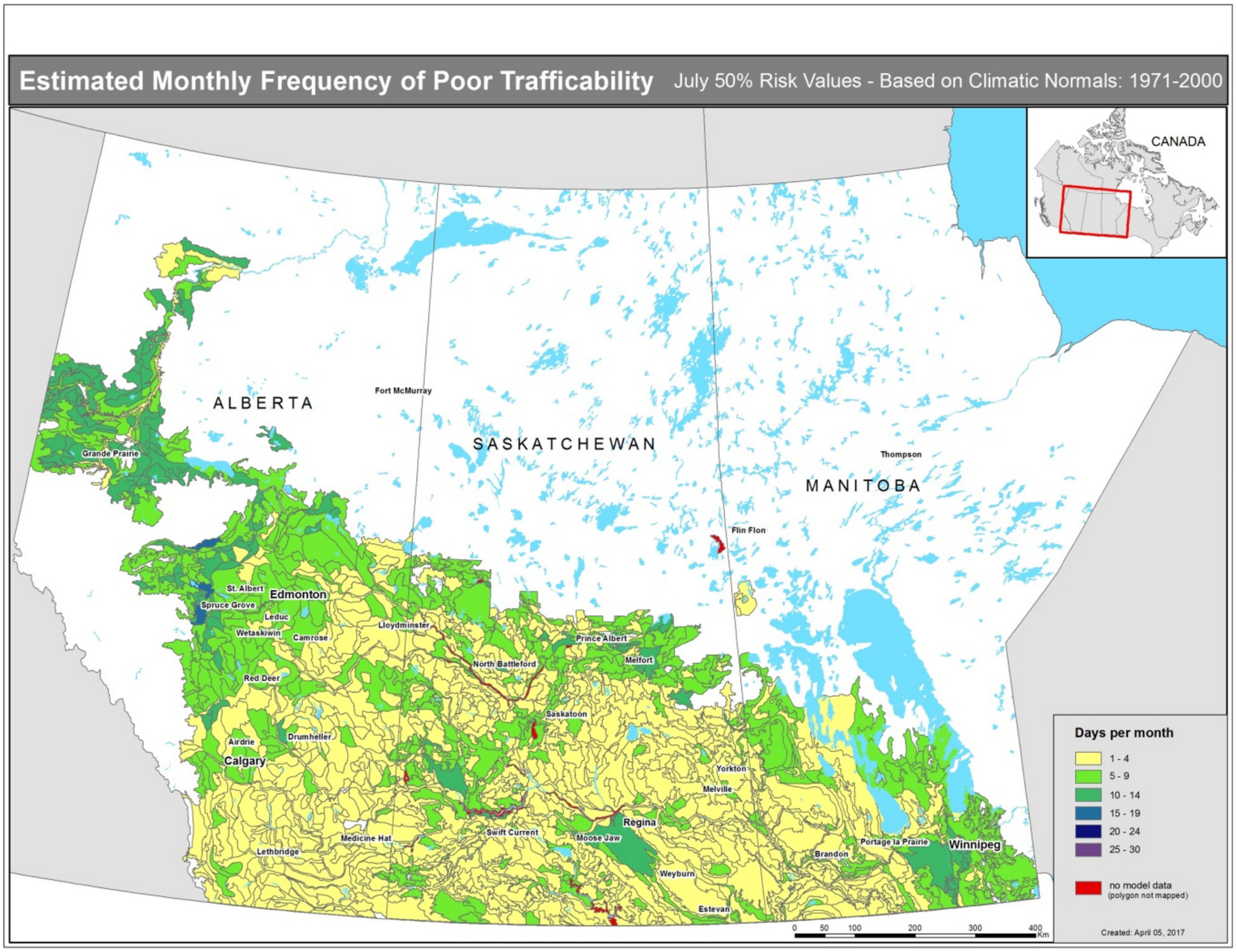

Fig. 2. The frequency of days with poor soil trafficability at mid-season (July) across the Prairie provinces at the a) 50th Percentile b) 75th percentile and c) 25th percentile levels. Maps do not reflect local or regional changes to soil drainage such as tile, modified surface and regional drainage systems. Soil trafficabilty was not assessed in polygons where the areal extent of the suitable classes for growing crops was less than 20%.

a) 50th Percentile. The map shows the frequency of days with poor soil trafficability at mid-season. Apart from eastern Manitoba and the northern portion of the Prairies bordering the boreal forest zone and extending into the Peace River Region of Alberta, the majority of the polygons in the southern grain belt had less than 5 days with poor soil trafficability during the month of July.

b) 75th Percentile. Under wetter than average conditions at mid-season, poor soil trafficability with a frequency of 5 to 9 days was widespread across the study area with exceptions in southern Alberta and southwestern and central Saskatchewan.

c) 25th Percentile. Under dry conditions, the majority of the polygons were trafficable at mid-season. The Peace River region from Alberta was an exception where some polygons had up to two weeks of non-trafficable days.

Climate data sets sere obtained from the 10 km gridded data (Hopkinson et al., 2011). Each polygon used all the climate grid points falling within the polygon and for smaller polygons which did not have a climate grid within its boundaries, climate grids were assigned to them using nearest neighbour analysis. The gridded climate data ranged from 1950 to 2015, and the climate period of 1971 to 2000 was used in this analysis.

2.3. Analytical techniques

Soil trafficability was assessed using soil moisture modelling, analysis of geo-referenced soil characteristics data and qualitative verification of land suitability rating to ensure that the results applied to agricultural units which are used for growing small grains (wheat, canola, barley, etc.).The following tools and analytical l techniques were used.

2.4. Versatile soil moisture budget (VSMB)

Soil moisture in the root zone to a depth of 120 cm was modelled using the Versatile Soil Moisture Budget (VSMB) (Baier et al., 2000). Modelled soil moisture values were used because the long-term in situ soil moisture measurements were not available temporally and spatially. The Versatile Soil Moisture Budget was run for all major soil types from each Soil Landscape of Canada (SLC 3.2). The soil moisture content for each layer was arrived at after calculating the major components of the water budget (runoff, infiltration, evapotranspiration and deep drainage). The calculation of the major processes of the water

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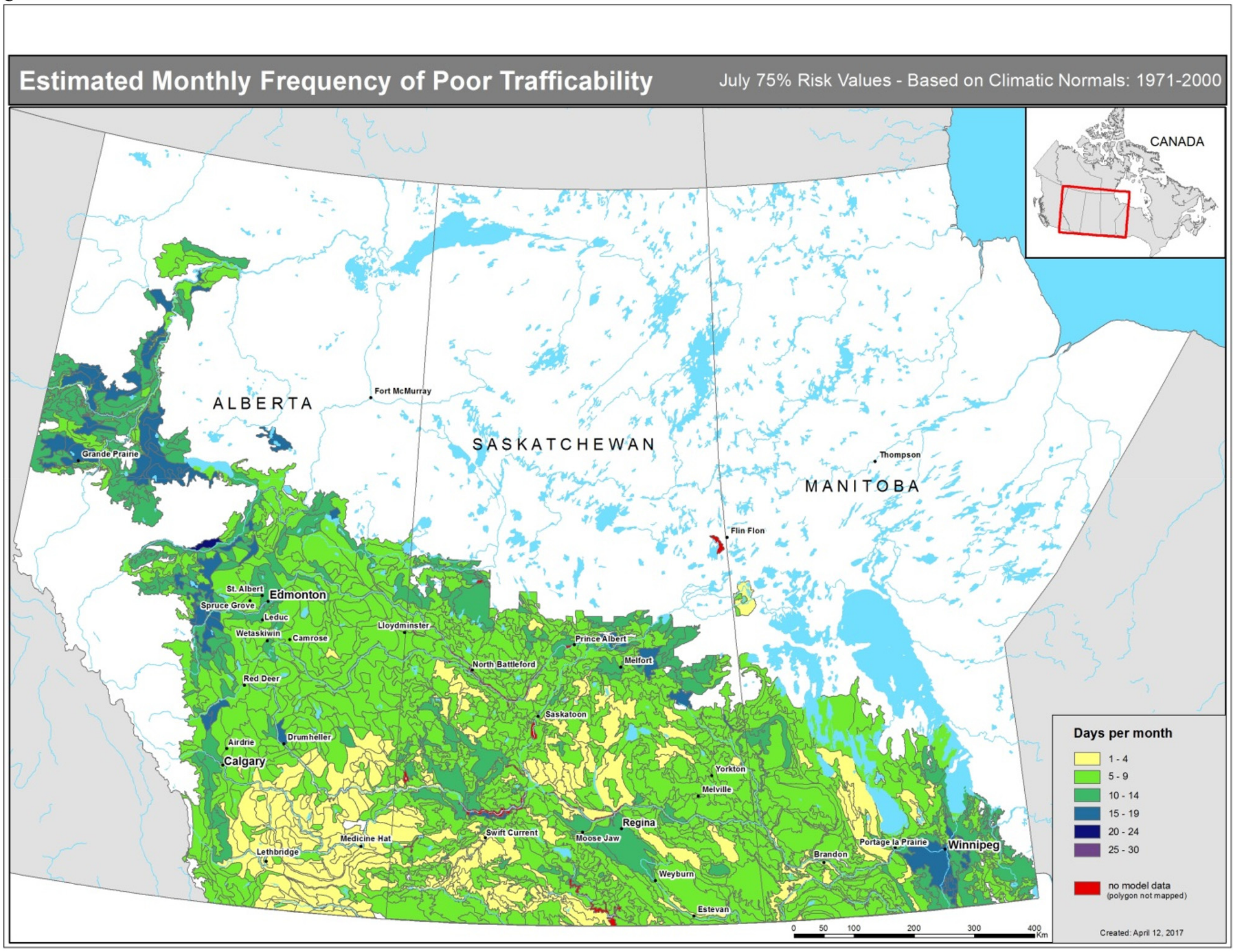

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budget model has been discussed fully in Akinremi et al. (1996); De Jong et al. (2009); Mohammed et al. (2013) and Chipanshi et al. (2013).The VSMB was run in continuous mode from April 15, 1971 to December 31, 2000 and this required the simulation of frozen water during the winter months (Arnold and MacKay, 1964) without re-initializing the model every year. For the initial run, the soil moisture content was assumed at 75% of the maximum possible. The outputs from this first simulation year were not included in any subsequent analyses (the first year was considered initialization). The soil moisture found in the upper surface of the soil (0 to 5 cm depth) was used to assess trafficability instead of the entire profile because the first few centimetres of the soil impact vehicular traffic on contact. Based on the areal extent of all soil components within an SLC polygon, an area weighted trafficability value for each SLC was calculated, however, the original rating for each soil component in the database was preserved for future analysis.

2.5. Land suitability rating system (LSRS)

Soils that are suitable for annual cropping were determined from the Land Suitability Rating System (LSRS) (Pettapiece et al., 2007). The LSRS is an interpretive software which is used to rate the suitability of land for spring-seeded small grains after taking into account the major limitations that inhibit crop production. Limitations for crop growth and production include insufficient heat units, high water demand (the difference between precipitation and potential evapotranspiration) and poor surface and subsurface soil characteristics (e.g. steep slopes and hard pans below the soil surface). Given that heat and moisture requirements are crop specific, Effective Growing Degree days (EGDDs) applicable to the crop were calculated from seeding to maturity using the Biometeorological timescale phenology module (Robertson, 1968). Starting with an ideal rating where maximum points were first assigned, points were deducted based on heat, water and soil categories and ending up with seven classes of land suitability (1 to 7), with class 1 being soil polygons with the highest suitability or least limitations and class 7 being the lowest suitability. The full details of the rating system can be found in Pettapiece et al. (2007). Regional land use experts were consulted to confirm the suitability rating value from the LSRS and polygons with questionable rating values were not included in the analysis.

2.6. Percentile classification of soil moisture

A percentile system (Spiegel, 1961) was used to classify the number of days with poor, average or good trafficability within a month. Poor trafficability thresholds were set at ≥80% of field capacity for clay soils (> 40% clay content) and ≥90% of field capacity for all other textures as per expert recommendation by Shaykewich (2006, Pers. Comm.). For

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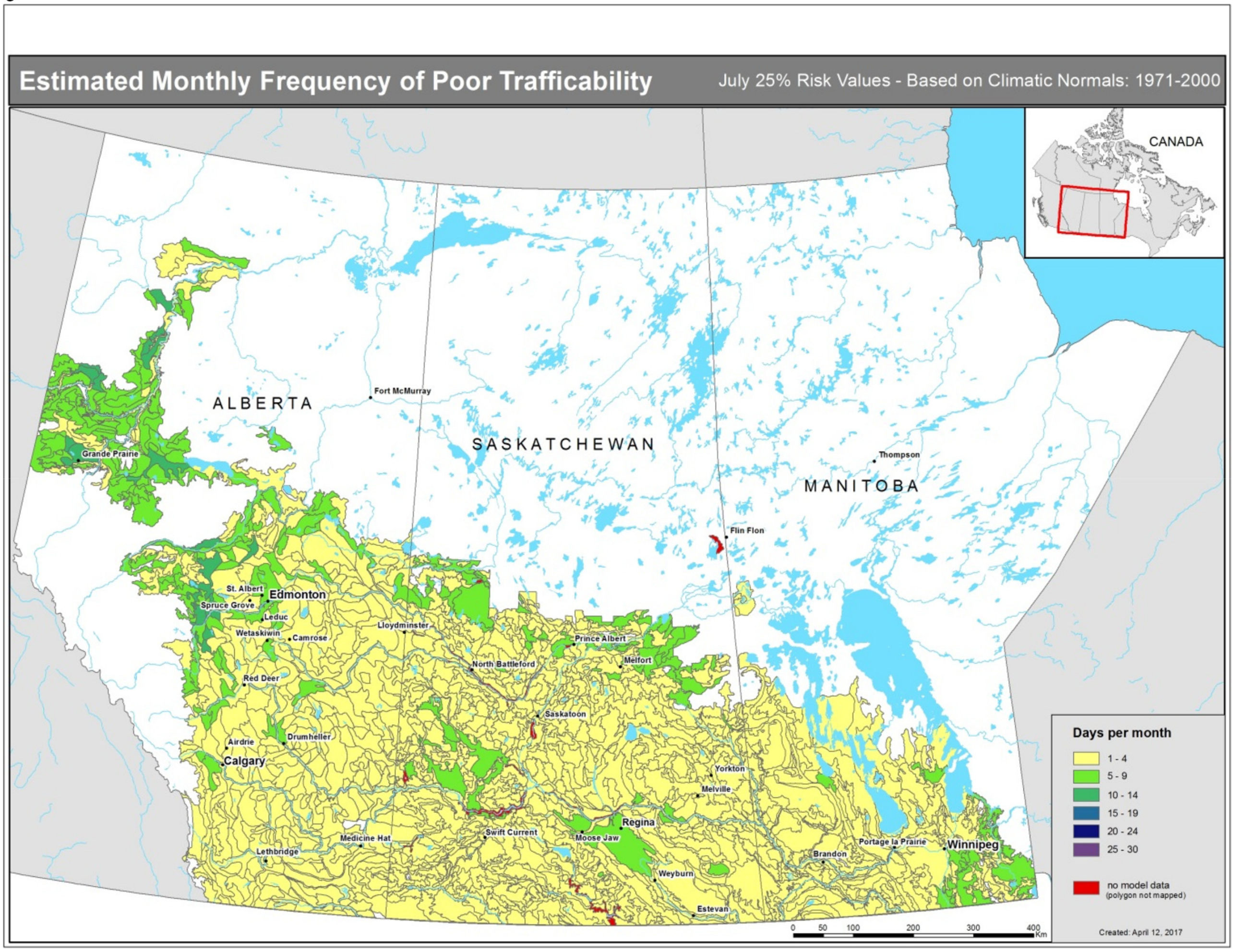

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each month, starting in the spring and ending in the fall, results were bootstrapped into three percentile categories to reflect the highest risk (25th percentile), average conditions (50th percentile) and better than average conditions (75th percentile). This included first ranking the daily soil moisture values from the lowest to the highest for each month for the entire period of record. The lowest 25th percent were classified as the 25th percentile, the top 75th percent and over were classified as the 75th percentile and the rest were the 50th percentile. An interquartile range (the difference between 75th and 25th percentile) was also calculated to show the variability in trafficability. For each of the three percentile categories, frequency maps were produced showing the number of days in a month with poor soil trafficability when field activities could negatively impact soil structure and production potential. Mapping was done using ArGIS 10.1 (ESRI, 2011).

3. Results

Soil trafficability was summarized at monthly time scales from April to September at the 25th, 50th and 75th percentile levels. For efficient discussion of results, the monthly time scales were further binned into start, middle and end of the growing season months which broadly corresponded to the following respective activities on the agricultural calendar: seeding, crop management and harvesting. May was selected as the representative month for seeding, July for crop management and September for harvesting. These months generally coincided with seeding; farm management and harvesting times as reported in the provincial annual crop reports (e.g. see Saskatchewan Agriculture and Food, 1994).

On average (50th percentile), the majority of the soil polygons were in the lowest class of days with poor trafficability (1–4) which is preferred to the higher classes from the perspective of traversing the soil with machinery at the start of the growing season (May). Fewer days with poor trafficability in the month will allow more work to be done than when more days have poor trafficability. However poor soil trafficabilty (5–9 days) in Alberta and sometimes (10–14) days in the Alberta Foot Hills (polygons bordering the Rocky Mountains axis from north to south) as well as those polygons found in the Peace River region (the extreme north western agricultural region of Alberta) (Fig. 1a) was recorded in May. The Alberta Foot Hills ordinarily experience chinook winds which bring about warm conditions, but frequently experience spring storms which are associated with wetter conditions in the spring (Strong, 1997). Even though the rest of Alberta experienced fewer than 5 days of poor trafficability, there were pockets of SLCs to the northeast of Edmonton and around the Calgary-Drumheller region where trafficability was in the 5 to 9 days range. For the most part, seeding of small grains across Alberta is not seriously hampered during

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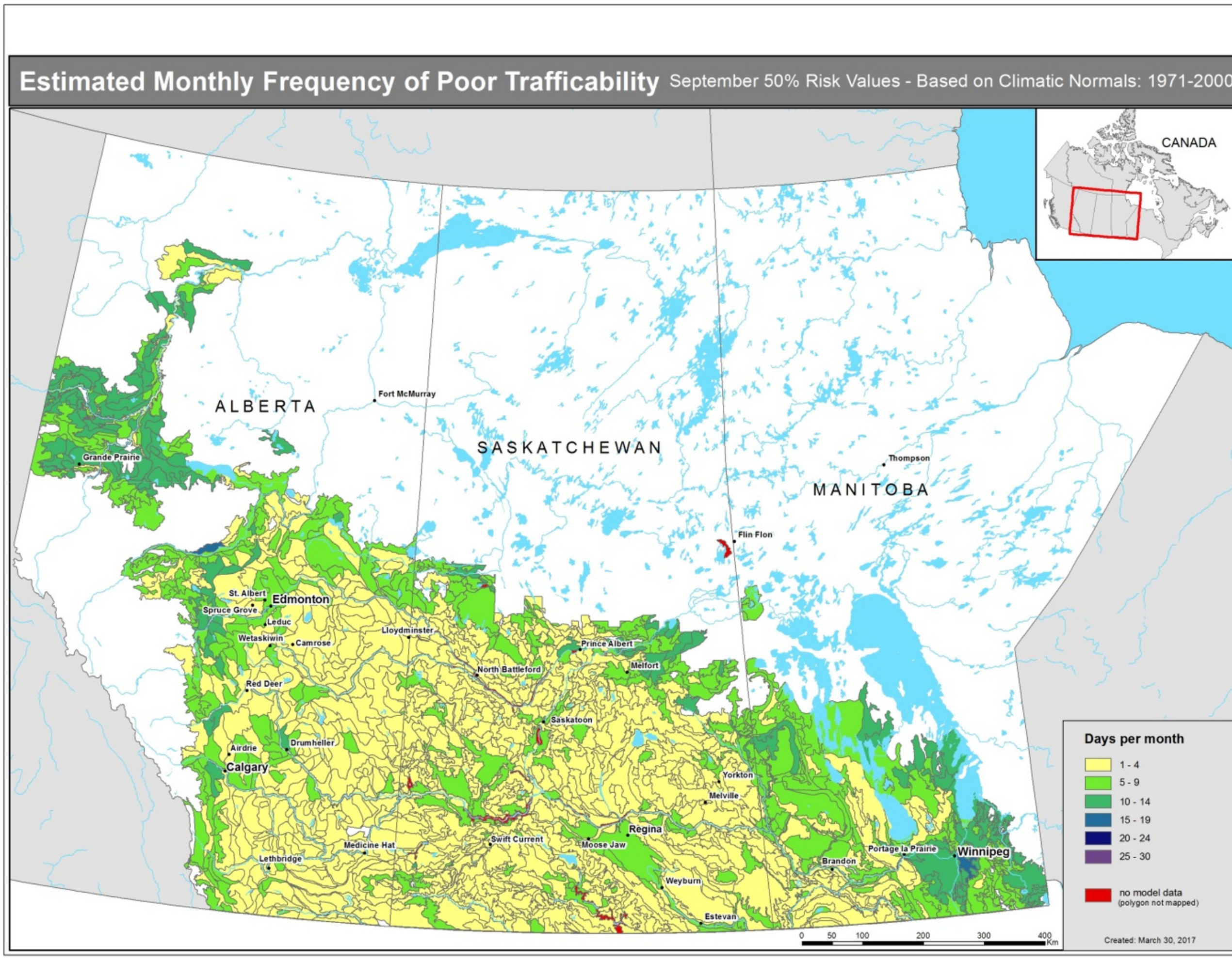

Fig. 3. The frequency of days with poor soil trafficability at harvest time (September) across the Prairie provinces at the a) 50th Percentile b) 75th percentile and c) 25th percentile levels. Maps do not reflect local or regional changes to soil drainage such as tile, modified surface and regional drainage systems. Soil trafficabilty was not assessed in polygons where the areal extent of the suitable classes for growing crops was less than 20%.
a) 50^{th} Percentile. At harvest time (September), eastern Manitoba and the northern portion of the Prairies bordering the boreal forest zone and extending into the Peace River Region of Alberta recorded the highest number of days with poor soil trafficability (10-14 days).
b) 75th Percentile. Under wetter than average conditions at harvest time, poor soil trafficability with a frequency of 5 to 9 days or more was widespread across the study area.
c) 25^{th} Percentile. Under dry conditions, the majority of the polygons were trafficable at harvest time except in eastern Manitoba and the Peace River region from Alberta where poor trafficability ranging from 5 to 9 days was recorded.

the month of May. The majority of the polygons in Saskatchewan did not have soil trafficability problems at the start of the growing season as most of them experienced 1 to 4 days of poor trafficability. There were exceptions nevertheless. Soil polygons around Regina, Moose Jaw, Weyburn, northwest of Swift Current and the northern boreal forest boundary (north of Lloydminister, North Battleford, Prince Albert and Melfort) had close to one week or more of days with poor soil trafficability. Polygons in these areas are associated with fine textured clay soils. In Manitoba, the zone with poor soil trafficability of close to one week (5 to 9 days) in May included an area covering eastern Manitoba below Portage La Prairie and extending into the northern Interlake region, as well as a few polygons in the north western region. This region has fine textured clay soils also. The rest of the western half of the province had 1 to 4 days with poor trafficabilty.

During wet years (represented by the 75th percentile) (Fig. 1b), the majority of the polygons across the Prairie Provinces experienced trafficability problems of up to a week or more in May. A few polygons from northwestern Alberta and central Manitoba (west of Winnipeg) were in the 15 to 16 days category. Relatively wetter soils in May could bring about drainage problems as this period is also affected by springmelt. With any spring storms, and depending on the over winter soil moisture reserves, any excess precipitation during the month of May can result in ponding or flooding of farm lands and other rural installations.

During dry years (represented by the 25^{th} percentile) (Fig. 1c), the majority of the polygons did not experience poor soil trafficability problems in May except those from the central region of Manitoba, south eastern Saskatchewan (Regina/Moose Jaw areas), parts of the Alberta Foot Hills and those from the Peace River region in Alberta. In the middle of summer (July) when the majority of the small grains are

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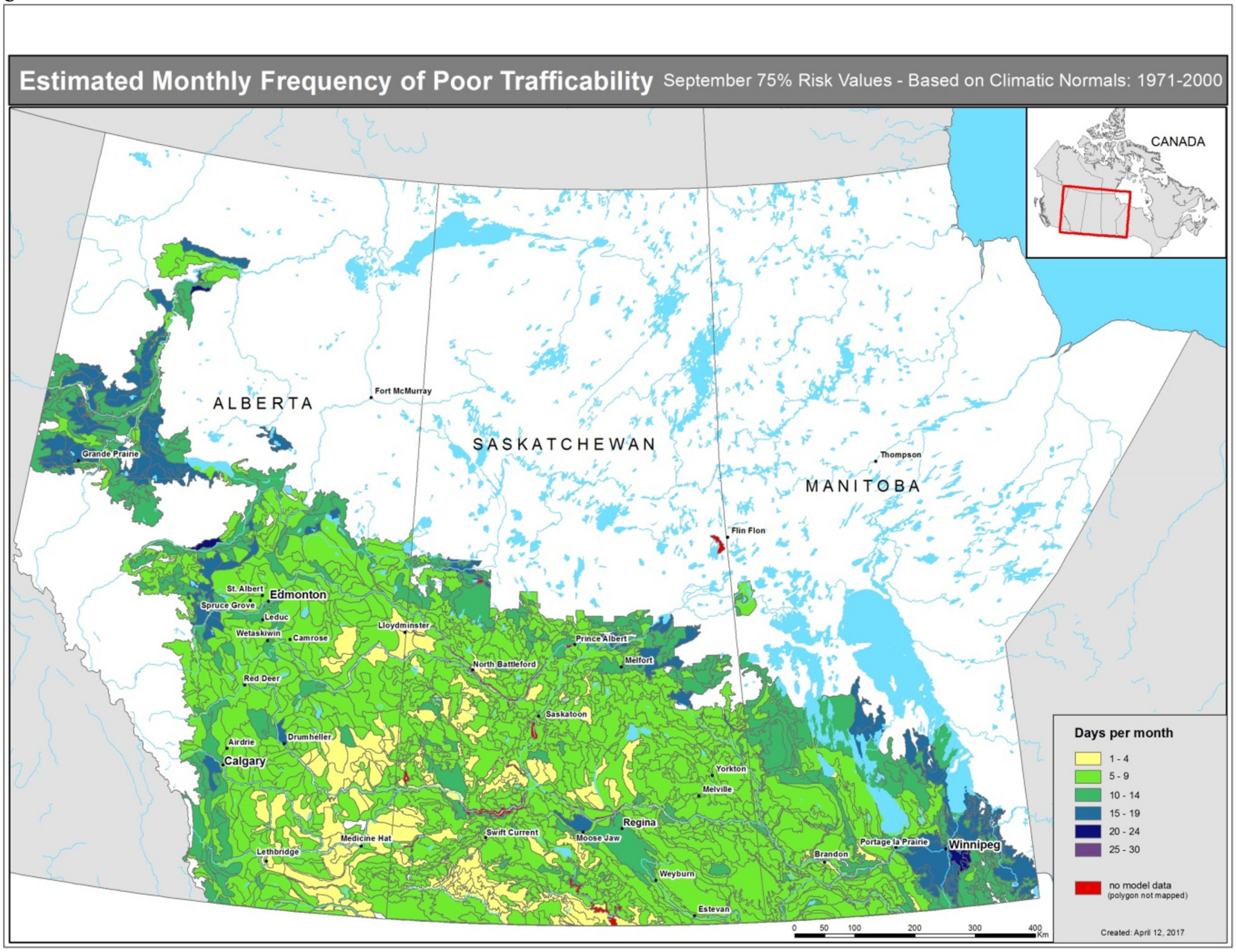

Fig. 3. (*continued*)

fully established, farm activities include managing the crop in terms of weed, pest and disease control and fertilizing. Poor trafficability was mostly found in northern Alberta and especially the Peace River region where the number of days with poor soil trafficability exceeded 2 weeks (Fig. 2a). In Saskatchewan the area which had poor trafficability at seeding expanded by July and included additional areas north of Lloyd Minister and North Battleford. In Manitoba, the pattern of SLCs with poor trafficability by mid-summer closely resembled the pattern at seeding time. There were more days with poor trafficability in the eastern half of the province and the Interlake region than the western half of Manitoba.

The pattern of the frequency of poor trafficability at mid-season in July at the 75th and 25th percentile levels (Fig. 2 b and c) was similar to the pattern at the start of the season in May (Fig. 1) with minor exceptions. Because the majority of the summer storms are received in July, areas which receive relatively higher precipitation totals as represented in the 75th percentile map (Fig. 2b) had more days with poor soil trafficability than those with relatively lower precipitation totals. In particular the area with poor trafficability expanded to northern Alberta (the Peace River region especially) where poor tafficability reached 15–19 days. Southern Alberta which lies in the rain shadow of the Rocky Mountains had fewer days with poor trafficability compared to the northern region. Similarly, there was an expansion of the area with poor soil trafficability in northern Saskatchewan compared to the south; a reflection of the difference in the total precipitation amounts received by each region. For relatively drier conditions in July (Fig. 2c-25th percentile), polygons with most days with poor trafficability were found in the northern fringes of the agricultural zone except in Manitoba where the eastern region still had the most days with poor trafficability.

At harvest time (September) (Fig. 3a, b and c), the majority of the polygons with poor soil trafficability were found in Manitoba which also had the most days with poor trafficability at the start and mid-season months under the average conditions. Moreover, the number of SLCs with poor trafficability days increased compared to the early and mid-season time periods. Over the long-term, only south western Manitoba had fewer days with poor trafficability at harvest time (Fig. 3a). In Alberta and Saskatchewan, soil polygons with poor trafficability at harvest time decreased or remained confined to the same areas which had poor trafficability at the start of the growing season and mid-season months.

During the relatively wet phases of the climate record (Fig. 3b), the frequency of days with poor soil trafficability was quite widespread and reaching 15–19 days in the Peace River Region of Alberta, the boreal transition zones of Saskatchewan and eastern Manitoba. During the relatively drier period of the climate record (Fig. 3c), the frequency of

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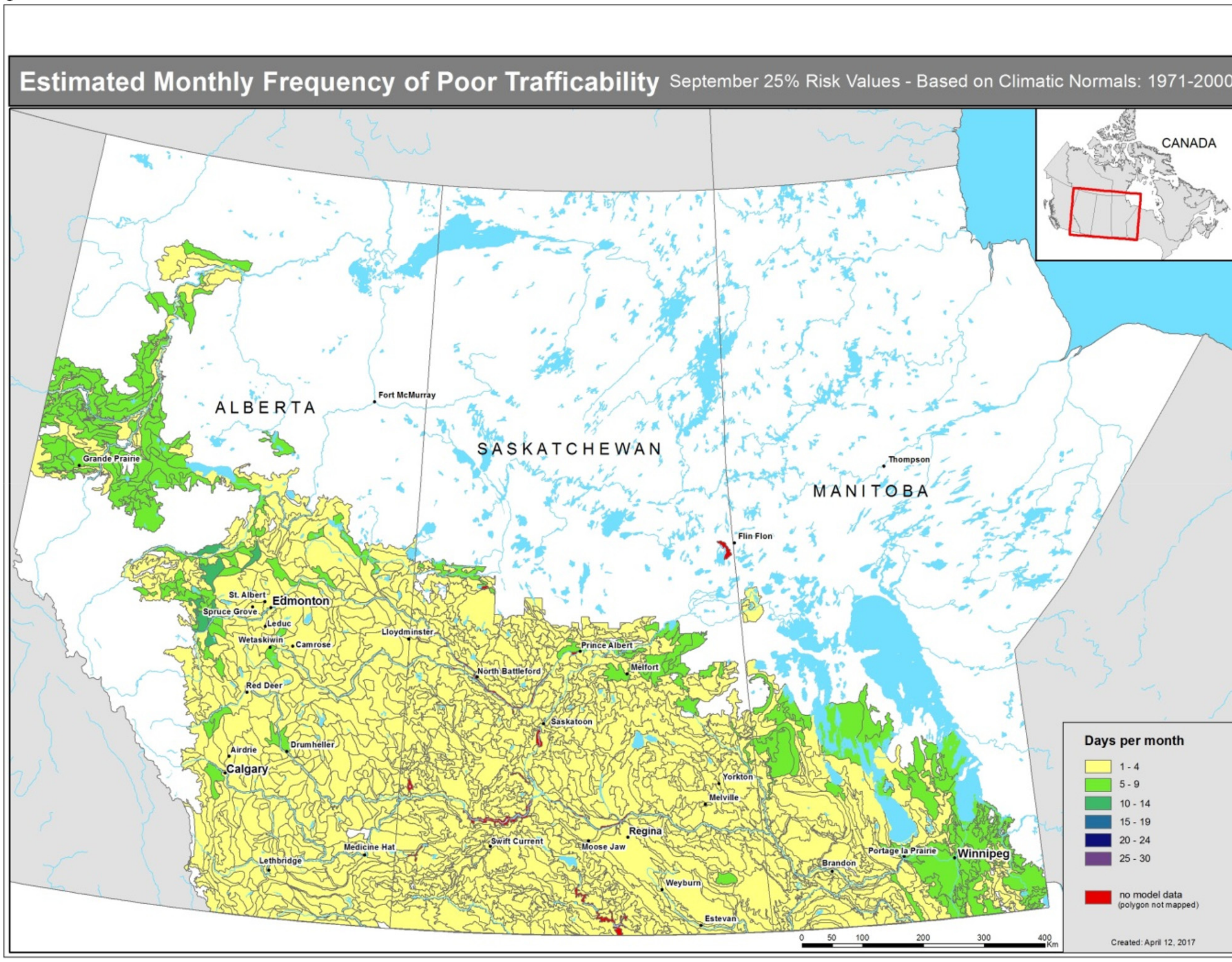

Fig. 3. (*continued*)

days with poor soil trafficability (5–9 days) was confined to the northern Peace River region of Alberta, northern Manitoba and the eastern region of Manitoba, while the rest of the prairie region had fewer than 5 days with poor soil trafficability.

Overall, we note that there were more soil polygons with poor soil trafficability in Manitoba than Alberta and Saskatchewan, irrespective of the soil moisture conditions as determined by the percentile classifications. Areas with the highest frequency of poor soil trafficability were also associated with high variability (Fig. 4) for the three time frames studied; May, July and September. The start (May) and end of the growing season (September) were more variable than the middle of the season (July). The majority of precipitation across the Prairie agricultural zone is received in July (Bonsal et al., 1999). As such there was consistency in the expected distribution of precipitation by month and the variability in soil trafficability.

4. Discussion

Ordinarily, the Canadian prairies are more likely to experience moisture deficits and leading to drought conditions than excess moisture which is often associated with soil trafficability problems. This generalization is based on the understanding that the majority of the prairie environment occupies a semi-arid to sub-humid climatic zone. According to Phillips (1990), the mean annual precipitation across the Canadian Prairies ranges from 250 mm in southwestern Saskatchewan/ south-eastern Alberta to 700 mm in the Manitoba Plain. The Soil Classification Working Group (1998) reported that the climate regions of the prairie environment closely matches the increase in organic matter from low, in moving from the semiarid zone in the southwest (predominantly Brown and Dark Brown Chernozemic soils) to high, in the sub-humid climatic zone of the northeast where the major soils are from the Black and Dark Gray sub groups. At the general level therefore, the depiction of regions with soil trafficability problems followed the environmental description of the prairie agricultural landscape in terms of soil texture and climate, particularly precipitation. We found an association between poor soil trafficability on one hand and heavy clay soils and high precipitation on the other. This was most explicit in the northeast and Inter-lake regions of Manitoba. However, this broad categorization was broken by site specific factors such as slopes and broad area depressions in some areas. The poor soil trafficability found in the Peace River region of Alberta for example is a combination of several factors including the valley like lowlands which may encourage moisture accumulation, clay textured soils and a boreal transition forest. Even though the Canadian prairie landscape is considered flat, it is now recognized that this may not be entirely correct with respect to describing the movement of water both laterally and vertically. In

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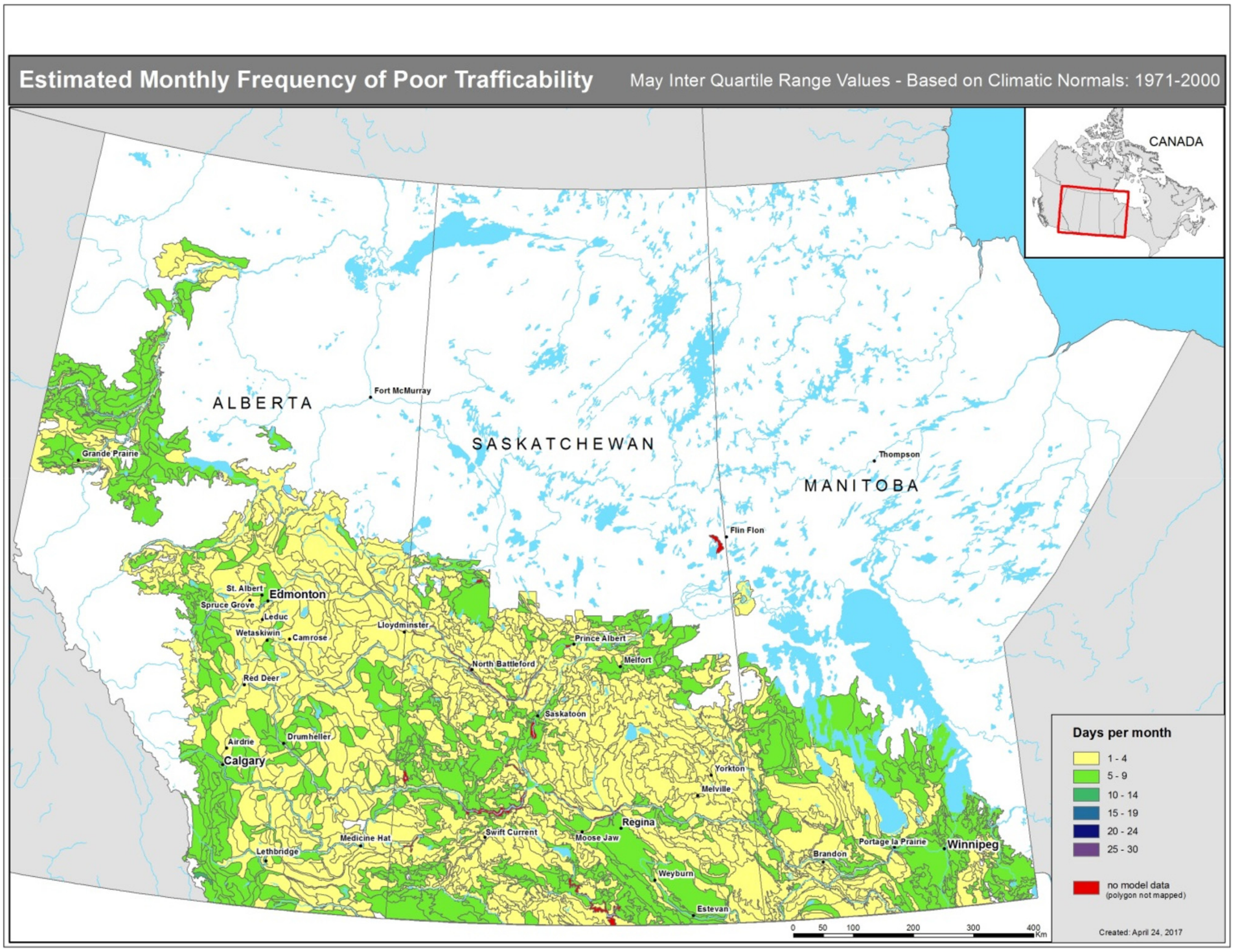

Fig. 4. The variability of days with poor soil trafficability at the start, middle and end of the growing season (difference between the 75th and 25th percentile thresholds). Local or regional changes to soil drainage such as tile, modified surface and regional drainage systems were not taken into account. Soil trafficabilty was not assessed in polygons where the areal extent of the suitable classes for growing crops was less than 20%.
a) May. Variability (IQR-Inter Quartile Range) in soil trafficability at seeding time (May). The majority of the polygons were in the 1-4 days category.
b) July. Variability (IQR-Inter Quartile Range) in soil trafficability at mid-season (July).Compared to early season, soil trafficability was less variable at mid-season. July has more reliable precipitation total than May and September on the Canadian Prairies.
c) September. Variability (IQR-Inter Quartile Range) in soil trafficability at harvest time (September).Manitoba, the Peace River Region and the Foot Hills from Alberta and the boreal forest boundary in Saskatchewan had the highest number of days with poor soil trafficability.

particular, the rolling prairie valleys and peaks which typify the majority of the agricultural landscapes consists of an interconnected series of ponds which may fill or empty by following complicated hydrological pathways (Shook et al., 2013).While droughts are more frequent than floods on the Canadian prairies, there is growing evidence that extreme wet events are also becoming more frequent (Brimelow et al., 2015) with the majority of the flooding occurring during the spring melt period. For low lying areas, such as the Assiniboine River basin in Manitoba, which are characterized by heavy clays, the risk of the land being unworkable due to poor trafficability is high and likewise the risk of delayed seeding is ever present. The association between heavy clay soils and poor soil trafficability was not limited to the early season only. We found poor soil trafficability at mid and (late) harvest seasons as well especially in eastern Manitoba, boreal forest fringes and the Peace River region in Alberta. Antecedent soil moisture conditions, the timing of precipitation events during the growing season and the site specific factors all contribute to the spatial distribution of the frequency of days with poor soil trafficability. Furthermore, a predominantly dry year does not preclude the occurrence of wet events within the year and vice versa. Szeto (2011) for example found that during the prolonged drought of 1999 to 2005 on the Canadian prairies, an extreme wet event occurred in 2002 in the middle of a major drought. Generally, poor trafficability at the start of the growing season results in delayed seeding. In the spring of 2007 for example, excess water in east central and northern agricultural regions of Saskatchewan led to a 25% reduction in seeded acreage (Saskatchewan Government, 2007). On the other hand, poor soil trafficability in autumn results in incomplete harvests by the time fall frost sets in. This was the case in 2016 in most parts of the southern grain belt of the Prairie Provinces where harvesting was suspended because of wet soils (Alberta Agriculture and Forestry, 2016; Saskatchewan Government, 2016).

The analysis of areas with poor soil trafficability has a number of

b

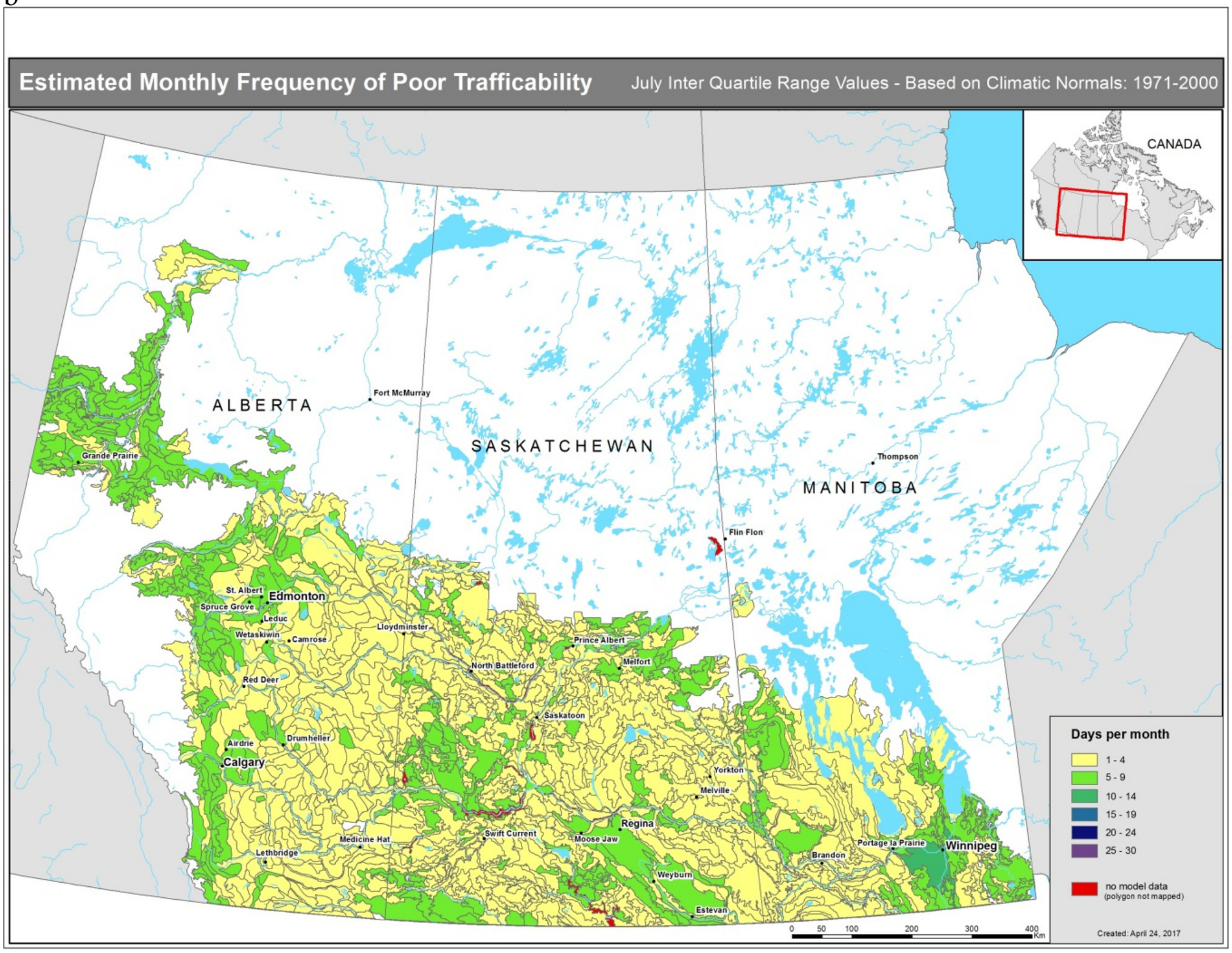

Fig. 4. (*continued*)

applications. From a soil management perspective, the long term trafficability maps provide additional planning tools for selecting areas for conducting some agricultural activity. In a review of how to manage excess water in Canadian prairie soils, Bedard-Haughn (2009) provided options such as the use of drainage, crop selection in a rotation sequence and tillage considerations as some of the actions that will help with reducing poor soil trafficability in some areas. The long term poor soil trafficability maps produced in this study provide the first step of identifying which areas can benefit from these interventions. Areas with poor soil trafficability are usually among the worst affected when agroclimatic conditions reach disaster proportion as was the case in 2006 when the economic cost of the crop insurance claims due to excess moisture in Saskatchewan alone for unseeded acres exceeded $61 million (Western Producer, 2006).

In trying to understand how climates of the future will affect soil trafficability, outputs of temperature and precipitation from climate change general circulation models can be used to simulate soil moisture conditions. The soil trafficability maps reported here will serve as a reference point against which to evaluate the future changes in soil trafficability. Preliminary results of how soil moisture will change across the prairies have been reported by McGinn and Shepherd (2003) using the Canadian Global Circulation Model. They found that there could be more soil moisture in the root zone (70 to 90 mm) in the future compared to the current amount of around 70 mm. This potentially indicates the possibility of poor soil trafficability in the future; however their results did not address the timing of the excess moisture.

5. Conclusions

We provided an assessment of soil trafficability across the Prairie agricultural region using the 10 km gridded climate data (1971–2000) and found that poor soil trafficabiity is mainly associated with fine textured clay soils. Soil polygons with poor soil trafficability were concentrated in eastern Manitoba, the northern fringes of the boreal forests found in northern Manitoba, Saskatchewan and Alberta, the northern Peace River region in Alberta and the Alberta Foothills. The soil trafficability maps are an effective planning tool for identifying potential problem areas and for use as baseline products for evaluating future soil trafficability under a changed climate. The quality of our assessment could have been affected by the limited field evaluation and confirmation of the land suitability ratings of soils used for growing the major grains across the Canadian Prairies. Field validation was mostly done in Alberta and Manitoba. The soil trafficability maps were provided for non-uniform soil polygons whose size varied according to attributes found in the component tables (e.g. soil type, slope, salinity, erosion etc.) at a very coarse scale of 1:1,000,000. This scale may not be

c

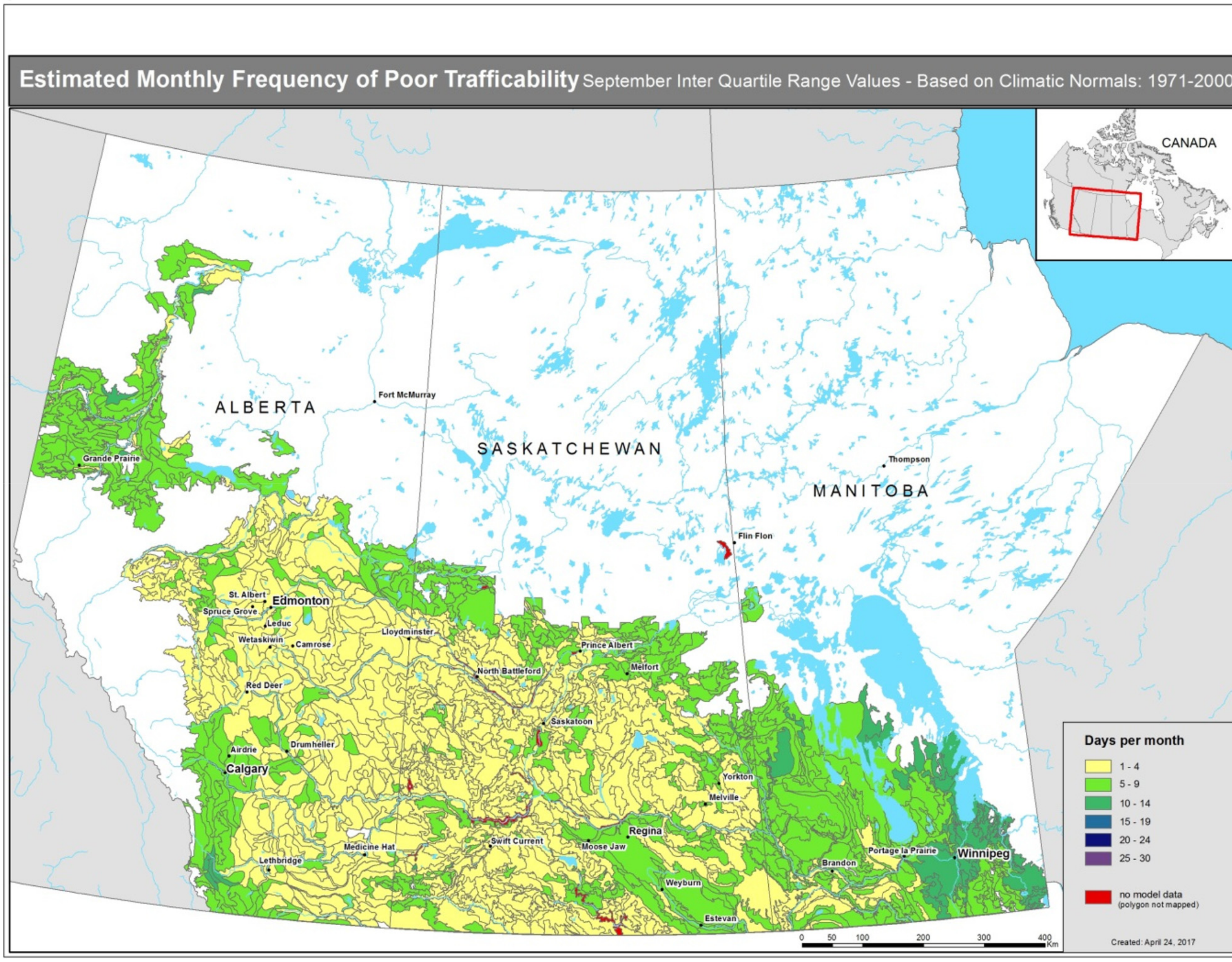

Fig. 4. (*continued*)

appropriate for farm level application. An alternative method of presenting the maps is by component soil type on which statistical analyses can be made.

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